Influence of Vegetable Inclusion in Rice Monoculture on Soil Organic Matter Quality under Sub-Tropical Climate

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Abstract

Soil organic matter (SOM) quality and its decomposability are influenced by cropping pattern. In particular, little is known on the specific difference in SOM quality under rice monoculture or combination of vegetables with rice culture. Therefore, four pairs of fields having vegetable-rice and rice-rice cropping pattern were selected from four different locations in Bangladesh, covering floodplain and terrace soils. Soils were first physically fractionated into particulate organic matter (POM) and silt and clay sized OM. The silt and clay sized OM was further chemically fractionated by oxidation with 6% NaOCl to isolate an oxidation-resistant OM fraction, followed by extraction of mineral bound OM with 10% HF (HF-res OM). The results show that there is a small increase in POM in vegetable-rice compared with monoculture rice soils. Among the fractions, a very large share of OM resided in NaOCl oxidizable OC and N in vegetable-rice soils. The silt and clay organic N was found to be more susceptible to NaOCl treatment compared with organic carbon (OC). Both the HF-extracted (HF-ex) and HF-res OC and N were found to be lower in vegetable-rice soils than in monoculture rice soils. Results from both physical and chemical fraction of SOM suggest that SOM accumulated in vegetable-rice cropping pattern are more labile than the solely rice based cropping pattern and prone to decompose quickly in any change of land use.

INTRODUCTION

Soil quality is largely regulated by soil organic matter (SOM). Most soil properties such as soil structure, water retention capacity, and diversity and activity of soil organisms are greatly influenced by the quantity and quality of SOM (Reeves, 1997). In addition, the role of soil organic carbon (SOC) within the terrestrial carbon budget as a sink for atmospheric CO_2 has received special attention (Lal, 2004; 2007). Therefore, SOM is considered to be a key attribute of soil quality, environmental quality, and agronomic sustainability (Reeves, 1997; Carter, 2002). SOM and particularly labile SOM fractions are dynamic properties that respond to changes in soil management (Zhang et al, 2006).

There is an increasing trend of change in land use from paddy rice to upland vegetables during dry winter period in Bangladesh. As a consequence, there was an increase of vegetable cultivation area from 244000 to 453000 ha between 1996 and 2007 with an average annual growth rate of 2.7% (FAO, 2009). This land use change was driven by several factors. Firstly, cultivation of vegetable in combination with rice during winter period is more profitable compared with solely rice based cropping pattern as the price and yield of vegetables is much higher than the rice. Secondly, there is a growing demand for fresh vegetables in market to meet the demand by rapidly growing urban areas and urban population. Thirdly, government in Bangladesh is encouraging farmers to cultivate diversified crop instead of monoculture rice to sustain soil fertility and to increase their income. Soil management practices in vegetable production are totally different than the rice cultivation. Rice is mostly grown under flooded conditions in bunded fields (paddies) with less fertilization and manuring. Farmers usually keep a very small part of rice straw (varied from 5 to 15 cm) in their fields after rice harvest including rice roots. In rice monoculture, land remains dry or flood fallowed during the turnaround period between two rice crops. Following these cultural practices, two or three crops of rice in sequence are grown in a solely rice based cropping pattern. On the other hand, vegetables are grown in dry land condition with intensive fertilization and manuring (Chen et al, 2004). In some vegetable fields, farmers use mulching to maintain soil temperature and moisture. Farmers also leave some crop residues in vegetable fields after harvest. Therefore, the accumulation and stabilization process of SOM may be largely different between vegetable-rice and monoculture rice cropping pattern and this could resulted different in SOM quality. Therefore, this study attempts to examine to what extent the vegetable based cropping patterns are different from traditional monoculture rice cropping patterns in terms of SOM quality.

MATERIAL AND METHODS

Site description and soils

Four pairs of fields having vegetable-rice and rice-rice cropping pattern were selected from four different locations of Bangladesh covering two major soil types, namely very younger floodplain and older highly weathered terrace soil. The locations were: Chandpur (Fields 1 and 2), Rangpur (Fields 3 and 4), Bogra (Fields 5 and 6) and Netrokona (Fields 7 and 8). This cropping pattern has been following for the selected fields since last 10-15 years. However, some years farmers keep fallow their lands or change the cropping pattern due to unfavourable environmental conditions such as flooding or poor marketing situation such as very low price. Fifteen soil samples were taken at each plot by means of an auger (Ø 2.5 cm) within a 25m x 40m rectangle. Basic properties of the soils are given in Table 1. The four vegetable-rice grown fields were each paired with monoculture rice grown fields with comparable soil type and texture, because of the major influence of these factors on C and N dynamics in soil. Bangladesh has a subtropical monsoon climate with a hot and rainy summer and a pronounced dry season in the cooler months. The annual mean temperature and precipitation of Bangladesh are 25°C and 2320 mm, respectively. Vegetables are grown in Bangladesh mainly during the dry and cooler winter.

Fractionation of soil organic matter

An ultra sonication-sedimentation method was used to physically fractionate particulate organic matter (POM) from the silt and clay sized SOM based on the procedure outlined by Amelung et al. (1997). Whole soil samples were dispersed at a low level of ultra sonication energy (60 J ml^{-1}) to breakdown the macro and micro aggregates. The silt and clay fraction (<50 µm) was then subjected to a chemical fractionation procedure according to Mikutta et al. (2006) and slightly modified by Sleutel et al. (2009), which involves sequential oxidation with 6% NaOCl and mineral extraction with 10% HF. The procedure results in the isolation of 1° a chemically stable 6% NaOCl resistant SOM fraction composed of mineral-protected as well as biochemically recalcitrant OM and 2° a biochemically non-bound recalcitrant SOM fraction (Fig 1). A 5g silt and clay sized sample was reacted three times for 6 h with 50 ml 6% NaOCl adjusted to pH 8.0 inside 85 ml nalgene centrifuge tubes. Samples were centrifuged and decanted in between oxidation cycles and were ultimately washed one time with 1M NaCl and three times with deionized H_2O. After drying and weighing, a sub sample was used for total C and N analysis. Then, 3g of the oxidation residue was treated four times with 20 ml 10% HF in order to dissolve and remove mineral constituents and mineral-bound OM. Extraction residues were washed five times with deionized H_2O to remove salts and residual HF and were dried and weighed. Chemical fractionations were carried out in twofold.

Carbon and nitrogen analysis

Both the OC and N content from all the fractions were determined by elemental analysis (Variomax CNS-analyzer, Elementar Analysesysteme, Germany). Absolute amounts of C and N in the different fractions expressed in g kg^{-1} were calculated from the relative dry matter weight of each fraction and its percentage of C and N.

Statistical analysis

All statistical tests were conducted with the SPSS 15.0 package (SPSS Inc., Chicago). ANOVA ($P=0.05$) was used to test differences in the SOC and N distributions over physical and chemical fractions between vegetable-rice and monoculture rice soils.

RESULT AND DISCUSSION

Physical fractions

The absolute as well as relative amounts of OC and N in POM fraction were not found to be consistently either higher or lower with a vegetable-rice cropping pattern as compared with monoculture rice soils (Table 2). However, when averaged over all four locations, a higher amounts of POM OC and N were observed on an absolute as well as relative basis in soils having a vegetable-rice cropping pattern (on average 3.05 and 0.24 g OC and N kg^{-1} soil, respectively accounting 30.5 and 22.5% of SOC and total N, respectively) compared with the monoculture rice soils (on average 2.9 and 0.2 g OC and N kg^{-1} soil, respectively accounting 29.5 and 20.0% of SOC and total N, respectively) though the differences were not significant. The C:N ratio in POM fraction was smaller in soils having vegetable-rice cropping pattern (on average 14.1) compared with monoculture rice soils (on average 15.6). As a consequence of the relatively higher contribution of the OC and N in the POM fraction, the absolute as well as relative content of silt and clay OC and N was lower in soils with vegetable-rice cropping pattern (on average 6.78 and 0.79 g OC and N kg^{-1} soil, respectively accounting 69.5 and 77.5% of SOC and total N, respectively) compared with the monoculture rice soils (on average 7.17 and 0.84 g OC and N kg^{-1} soil, respectively accounting 70.1 and 80.1% of SOC and total N, respectively). A larger relative proportion of silt + clay associated N (78.8±8.9% of total N) compared with silt + clay associated OC (69.9±7.2% of the total OC) was observed for all the sites, reflecting the often reported enrichment of N with decreasing particle size (Leinweber and Schulten, 1995, Kader et al, 2010a).

Higher POM OC and N content in soils having vegetable-rice cropping pattern with low C:N ratios could be attributed to the farmers practice keeping vegetable crop residues in their fields after harvest. In addition, sometimes farmers use mulching materials (e.g. water hyacinth, straw, banana leaf etc.) in their fields to keep the soil warm during winter and to protect soil from evaporation. Vegetable crop residues and mulching materials are in general enriched with N (Chaves et al, 2008) compared to rice crop residues. Logically the C:N ratio of POM was found to be smaller in soils with vegetable-rice cropping pattern compared with the monoculture rice soils.

Chemical N fractions

The silt and clay fraction of SOM contained the majority of OC and N in the studied soils. This fraction was further fractionated into NaOCl oxidizable (NaOCl-ox), HF extracted (HF-ex) and HF resistant fractions (HF-res). The size of the OC and N fractions obtained from the chemical fractionation of silt and clay sized OM, expressed on a bulk soil basis (g kg^{-1} soil), is given in Table 2. Briefly, the NaOCl oxidation removed substantially larger amount of OC and N from soils with vegetable-rice cropping pattern compared with their corresponding monoculture rice soils in all the four locations on a relative basis except Chandpur (Fig 2). On average, NaOCl oxidized significantly higher percentage of silt and clay sized N and OC for soils with a vegetable-rice cropping pattern (70±8 and 50±13% of silt and clay sized N and OC, respectively) compared with monoculture rice soils (54 ± 8 and 40±9% of silt and clay sized N and OC, respectively). This result corresponds with Kader et al. (2010b) who found that 52±5% of the silt and clay sized N (i.e. 45±5% of soil N) was oxidized by NaOCl in Belgian arable soils with a cereal-root crop rotation. NaOCl oxidation selectively removed larger amount of N compared with OC regardless of cropping pattern. The higher amount of NaOCl OC and N in vegetable-rice soils suggests that SOM in vegetable-rice soils are more labile in character.

Subsequent mineral dissolution by 10% HF released on average 49±18 and 26±10% of NaOCl-res N and OC which is similar with the previously reported released of 48±12% of the NaOCl-res N by Kader et al. (2010b). HF extracted a smaller proportion of N and OC from vegetable-rice soils compared with the monoculture rice soils in all the four locations (Fig 2). However, the difference in HF-ex N and OC between soils from to land use group was not found to be significant. On an absolute basis, Rangpur was an exception (Table 2) and this could be due to the fact that in this location sometimes rice (transplant Aus rice) is cultivated during the fallow period succeeding to vegetables. Relative content of HF-res OC and N also followed the similar pattern in all the locations like the HF-ex OC and N (Fig 2). On average, HF-res OM represented 10±3 and 25±5% of total N and SOC for the soils with vegetable-rice cropping pattern whereas it represented 17±4 and 29±3 of total N and SOC for rice soils. Higher proportion of HF-resistant SOM in rice soils compared with soils from vegetable-rice cropping pattern may be due to the fact that there was more accumulation of lignin residues and N poor OM in monoculture rice soil. In rice monoculture two or three rice crop is cultivated per year and soil remains submerged for longer period which favoured accumulation of less humified SOM with larger molecules (Olk et al, 2000) and lignin residues in soils (Olk et al, 2002).

CONCLUSIONS

There is a shift in composition of SOM towards a more labile character in soils with vegetable-rice cropping pattern may be due to the farmer’s practices keeping some crop residues and mulching materials in their fields after harvest. On the other hand, the nature of the SOM accumulated under rice monoculture is relatively more resistant with accumulation of lignin rich residues. However, the observed differences were not statistically rigorous as the soils were sampled from the farmer’s fields where they did not maintain same cropping pattern and management practice every year. Intensively managed long term experimental soils could be the ideal one for such type of study.

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Tables

Table 1 Selected soil properties of the sampled soils (0-15 cm depth layer).

Field	Site	Soil particles (g 100/g soil)			OC (g/kg soil)	TN (g/kg soil)	C:N	pH_{KCl}
		>50 μm	2-50 μm	<2 μm				
	Chandpur							
1	Vegetable	9	79	12	9.98	1.06	9.42	6.3
2	Rice	14	79	7	11.44	1.20	9.53	6.1
	Rangpur							
3	Vegetable	27	60	13	9.95	0.96	10.36	5.8
4	Rice	71	19	10	6.48	0.69	9.39	5.8
	Bogra							
5	Vegetable	19	65	16	12.35	1.50	8.23	5.9
6	Rice	17	48	35	13.20	1.38	9.57	5.7
	Netrokona							
7	Vegetable	29	62	9	8.13	0.76	10.70	5.8
8	Rice	28	52	20	10.72	1.24	8.65	5.8

Table 2 Amounts of total N (g N kg soil^{-1}) and C:N ratios of the isolated physico-chemical fractions (average ± standard deviation) .`

Fields	Site	Particulate OM (POM)		Silt and clay fractions					
				NaOCl-oxidizable OM (NaOCl-ox)		NaOCl-resistant OM			
						Extracted by HF OM (HF-ext)		HF-resistant OM (HF-res)	
		N	C	N	C	N	C	N	C
	Chandpur								
1	Vegetable	0.43	4.96	0.49±0.07	3.21±0.41	0.07±0.05	0.18±0.09	0.10±0.04	2.06±0.62
2	Rice	0.28	3.49	0.54±0.11	3.68±0.51	0.06±0.03	0.62±0.23	0.28±0.06	3.01±0.66
	Rangpur								
3	Vegetable	0.14	2.07	0.56±0.01	2.55±0.12	0.17±0.09	1.55±0.45	0.14±0.07	3.12±0.56
4	Rice	0.17	1.81	0.23±0.03	1.54±0.16	0.15±0.02	1.02±0.13	0.11±0.01	1.81±0.21
	Bogra								
5	Vegetable	0.28	3.19	0.68±0.09	3.77±0.45	0.29±0.14	1.50±0.46	0.11±0.05	3.21±0.52
6	Rice	0.15	3.63	0.51±0.13	2.87±0.64	0.37±0.08	2.16±0.41	0.21±0.05	4.41±0.71
	Netrokona								
7	Vegetable	0.10	1.95	0.46±0.01	3.75±0.11	0.05±0.04	0.46±0.19	0.07±0.03	1.75±0.47
8	Rice	0.20	3.04	0.54±0.07	3.23±0.42	0.18±0.04	1.20±0.24	0.19±0.03	3.13±0.49
	Mean								
Vegetable		0.24	3.05	0.55	3.32	0.05	0.92	0.11	2.54
Rice		0.20	2.99	0.46	2.83	0.18	1.25	0.20	3.09
ANOVA		NS	NS	*	NS	NS	NS	*	NS

Figures

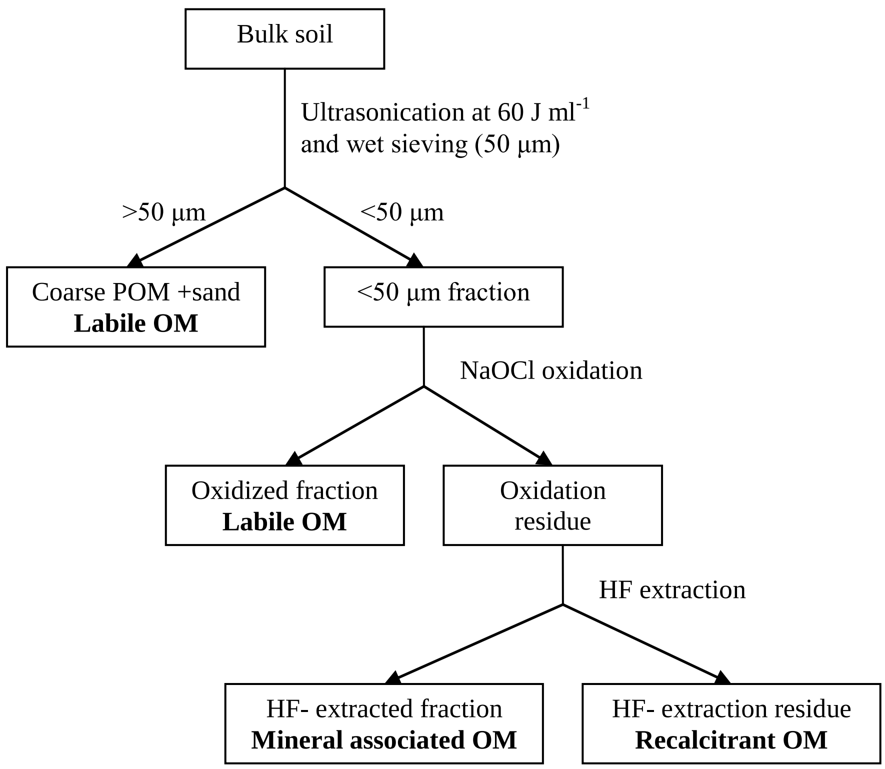

Figure 1. Combined Physical and chemical fractionation Scheme to isolate labile, mineral protected and recalcitrant organic matter.

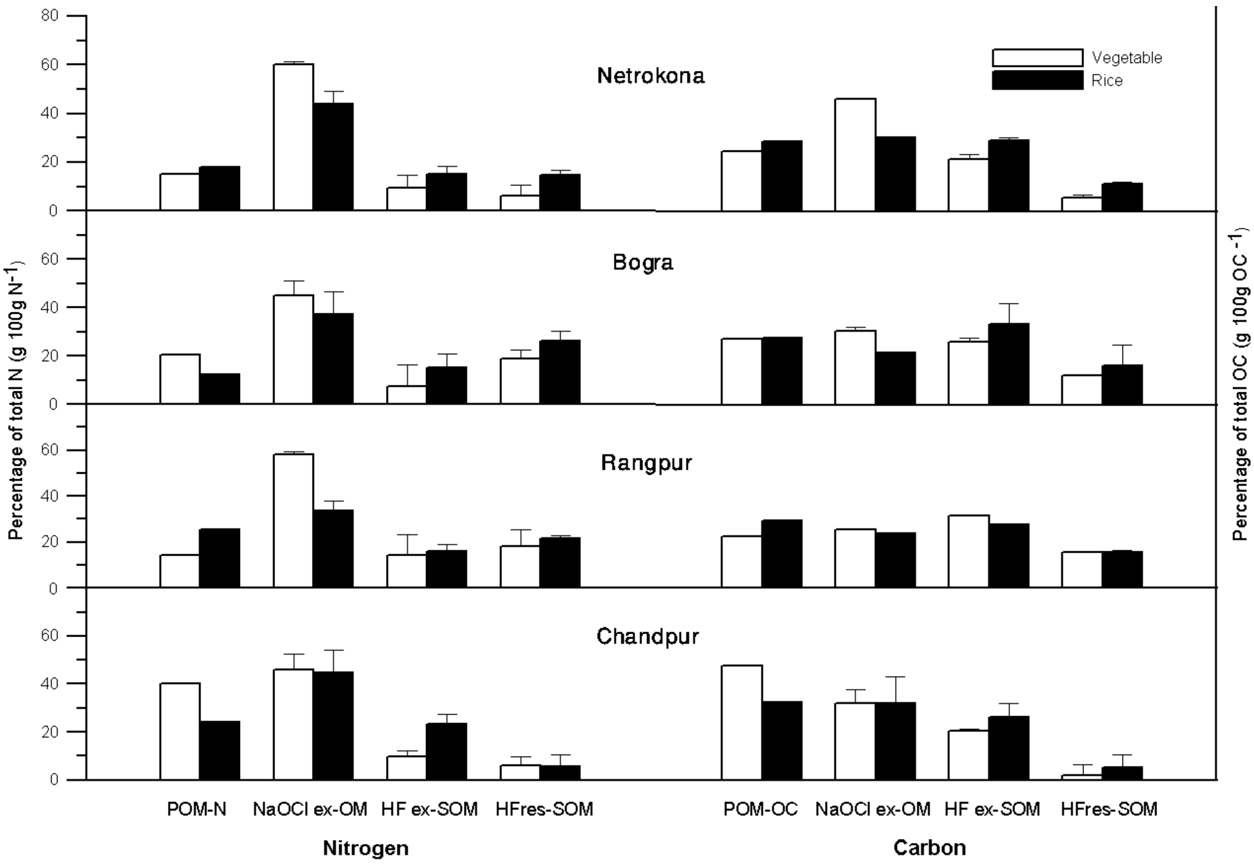

Figure 2. Relative distribution of the total N (left) and OC (right) over different SOM fractions for the vegetable-rice and rice-rice cropping pattern